Investigating the use of an electro-optic crystal to detect coherent THz synchrotron radiation

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INTRODUCTION

Electro-optic THz detection systems are very sensitive and can directly measure the electric field, not only intensity, of THz pulses. We want to determine if such systems could be used to detect coherent synchrotron radiation in a proposed new infrared ring at the ALS.

During the five past weeks we have experimentally investigated a femtosecond laser based THz system and have calculated the synchrotron intensity in the near infrared which could be used as the probe beam in a future synchrotron based THz system.

DETECTION OF THZ WAVES

We use laser pulses with 15 femtoseconds width and 1 nJ of energy. The beam is split into two. The more intense beam is used to generate THz waves, while the probe beam can be delayed or advanced by mirrors stuck on a loudspeaker. The THz and probe beams are focused on the ZnTe non-linear crystal, which has the following refractive index:

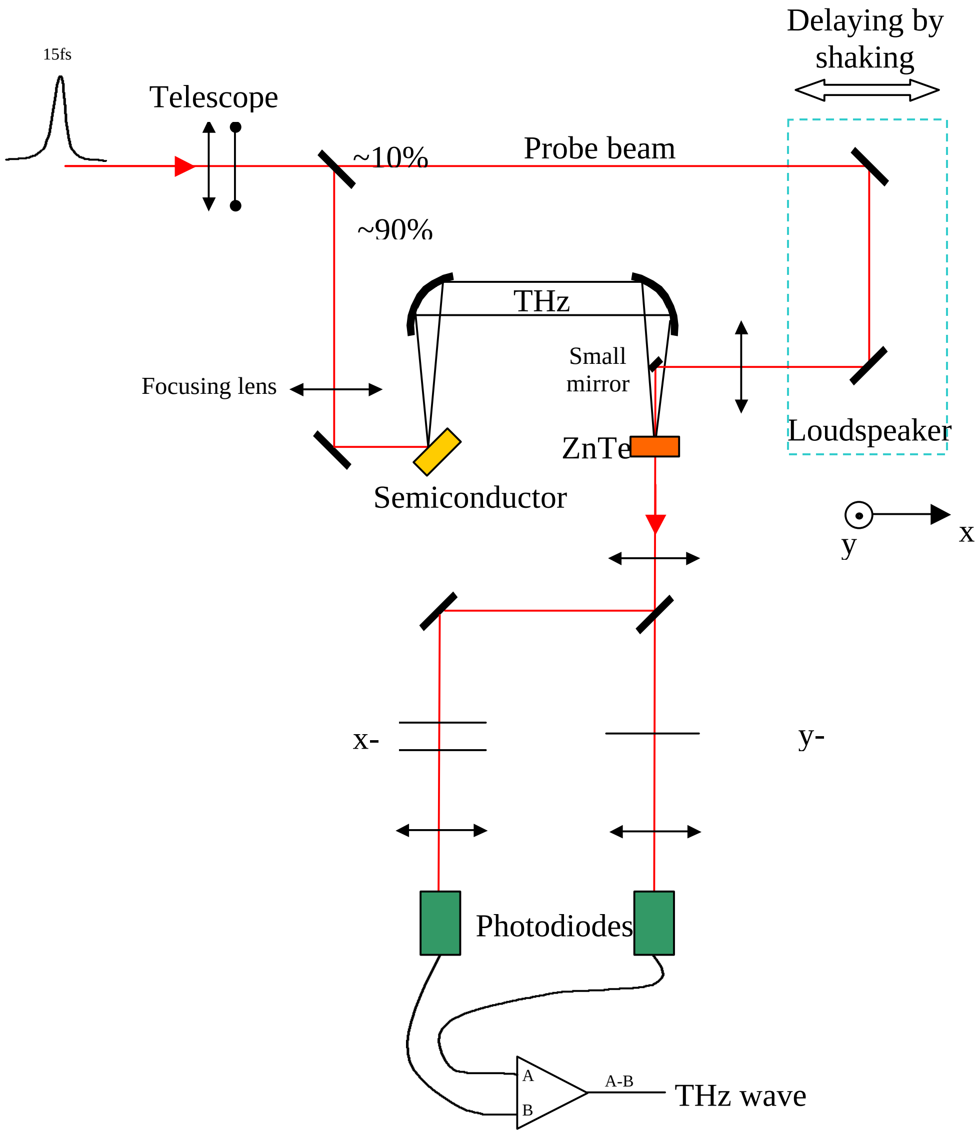
$$\begin{cases} n_x = n_0 \\ n_y = n_0 + aE_{THz}(t) \end{cases}.$$

Where $E_{THz}(t)$ is the THz electrical field and α a crystal carateristic coefficient. The vertical refractive index varies in time with the THz electrical field. Thus the y-component of the electric field of the probe beam is modified (polarisation rotation). The probe beam is not polarized, therefore the output of the ZnTe crystal can be written

$$\begin{cases} E_x = \dfrac{E_0}{\sqrt{2}} \sin wt \\ E_y \approx \dfrac{E_0}{\sqrt{2}} \left[\sin wt + k\, l a\ E_{THz}(t) \cos wt\right] \end{cases}$$

We have made a first order approximation on $\sin(k\, l\, a\ E_{THz})$, where l represents the crystal width. In measuring the probe beam vertical component we can obtain the value of E_{THz}. Every 8 nanoseconds a new laser pulse comes, the THz wave generated is 10^{-12} seconds broad, if we shorten or lengthen the probe beam path we can measure E_{THz} versus time.

To change the time delay of the probe beam, we apply a triangular signal to the loudspeaker. We suppose that the membrane displacement is proportional to the input signal, the proportionality coefficient is equal to 606 nm/mV if the input voltage is about 10-30 mV and the frequency is between 10 and 100 Hz. These figures were experimentally determined from a homemade Michelson interferometer using that same speaker.



If we subtract the *x* component from the *y* we get $E_{THz}(t)$ values directly, plus this has the advantage of decreasing the noise too.
If we are able to put the small mirror between both parabolic mirrors where the THz beam is larger, it may improve the Thz detection efficiency, keeping in mind that the two beams must have the same length coarsely. The main difficulty in our setup is to collect a high energy density on the semiconductor source, which should be about 40 mW (1.5 10^{17} photons/s, E_{photon}= 1.59 eV) over a 100µm^2 surface to generate sufficient THz intensity.

FLUX CALCULATIONS FOR THE ALS

The number of photons emitted by an accelerated electron on a circular path for frequency w is

$$\frac{d^2 n_{ph}}{r dx} \approx \frac{a}{l_f} \frac{dw}{rw}.$$

Where α is the fine structure constant and the formation length is given by

$$l_f = \sqrt[3]{24}\ r^{2/3}\ ƛ^{1/3},$$

r is the bending radius. We can find the number of photons according to the wavelength, far from the critical wavelength, where $ƛ = l/2p$,

$$\frac{d^2 n_{ph}}{r dx} \approx \frac{a}{2.9}\ r^{-5/3} ƛ^{-4/3} dƛ.$$

To have an accurate solution we have to multiply this formula by the factor 0.52/0.39. We have to consider the wavelength limitation due to the vacuum chamber. Using the condition coming from the wave-guide theory we obtain

$$l_{co} = 2p\sqrt{\frac{24d^3}{r}} \approx 1.4mm,$$

d represents the diameter, which is on the order of one centimeter.

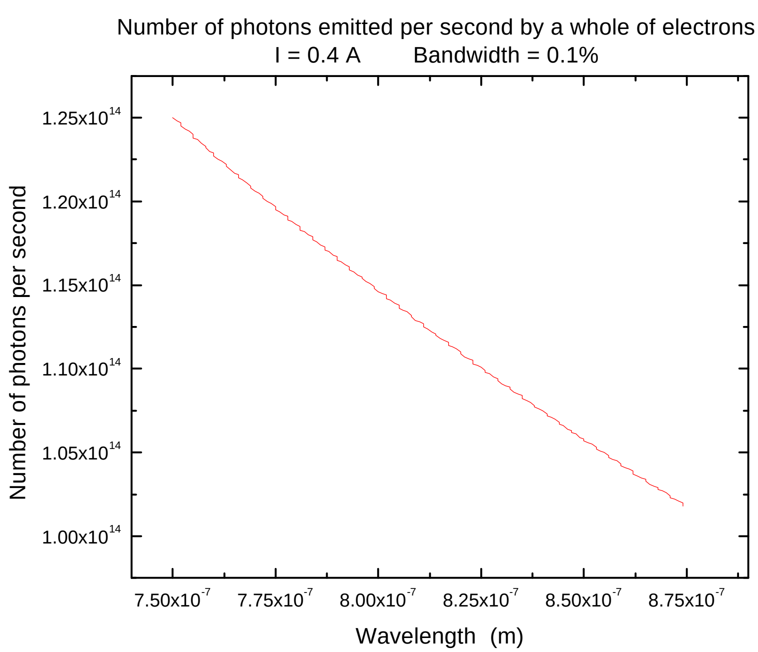
Using the following set of values, we can plot the number of photons emitted in 1 second from all electrons.

$$Current = 0.4\ A \Leftrightarrow Number\ of\ electrons\ per\ \mathrm{second} = 2.50\ 10^{18}$$

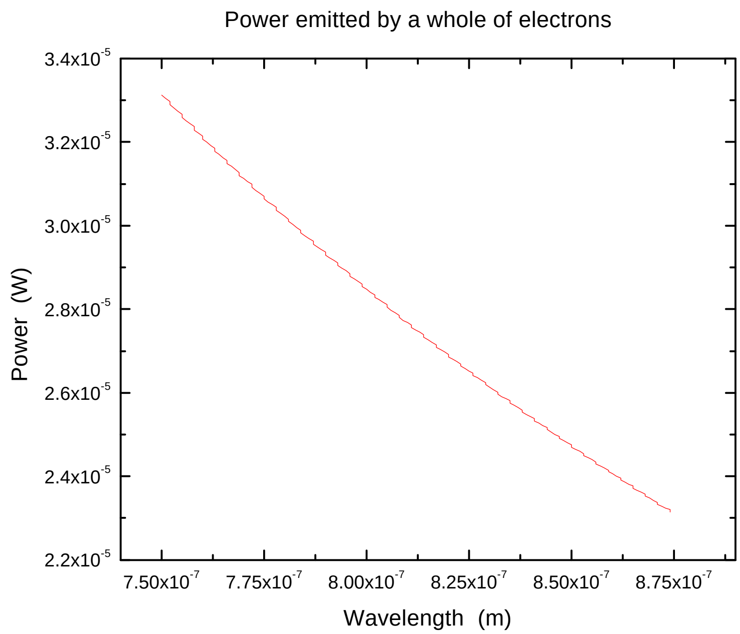
$$r = 4.81m$$

$$bandwidth = 0.1\%, i.e.\ d l = 0.001\ l$$

$$a \approx \frac{1}{137}\quad in\ I.\mathrm{S.\ units}$$



Thus the number of photons emitted per second is about $1.15\ 10^{14}$ at 800 nm wavelength and decreases with $l^{4/3}$. The Planck's relation allows us to calculate the power according to the wavelength which is decreasing with $l^{7/3}$.



For the proposed IR ring if we take $r = 1.55m$ and the current equal to 0.1 A, the number of photons emitted per second is about 1.89 10^{14} at 800 nm wavelength. If the current is 3.3 mA the number of photons per second is 6.25 10^{12}. These calculations are made for a 0.1% bandwidth but for THz detection the bandwidth may be higher, about 10%.

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